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# Demonstration of GaN HEMT MMIC High-Power Amplifier for Lunar Proximity Communications

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# Outline

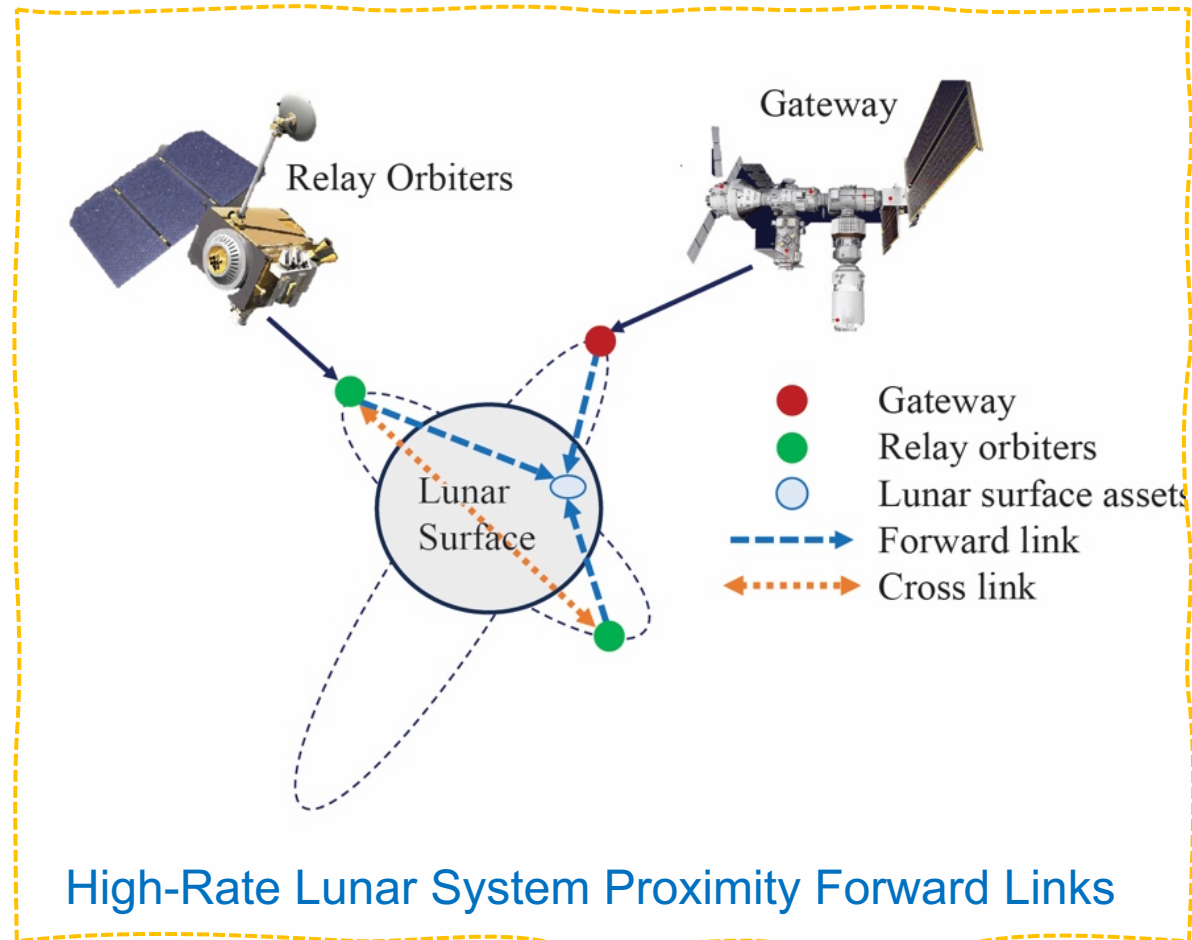
- Introduction
- Gallium Nitride (GaN) for High Power Amplifiers (HPAs) — Advantages
- HPA — Brief Set of Requirements
- Prototype Single Ended HPA — GaN MMIC Chips
- Measured Performance Characteristics
  - Output Power ( $P_{out}$ ) & Gain vs. Input Drive Power ( $P_{in}$ )
  - RMS Error Vector Magnitude (EVM) vs.  $P_{in}$  for Various Waveforms
  - Output Spectrum for Various Waveforms
  - Third-Order Intermodulation Distortion vs.  $P_{in}$  per Tone
  - Noise Figure & Associated Gain vs. Frequency
  - SSB Phase Noise vs. Frequency Offset from Carrier
- Conclusions & Discussions

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# Introduction

- The vision for NASA's Artemis mission is to enable human/robotic exploration of the Moon's surface/interior and provide a long-term presence on the Moon
- To achieve this vision, NASA plans to develop a lunar Gateway to serve as an outpost, human landing systems and ascent elements, relay satellites, surface habitats, terrain vehicles, and rovers



# Introduction

## (Continued)

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- In the above missions, to ensure astronaut's health and safety and for transferring science data from surface instruments to Earth, NASA plans to deploy robust communication links between the above surface elements and the orbiting Gateway/relay satellites
- Hence, there is a need to develop high power/efficiency amplifiers (HPAs) that operate at frequencies designated for this requirement
- Our extensive studies indicate that the preferred choice of semiconductor material for fabricating the transistors for the HPA is GaN

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# GaN for High Power Amplifiers

## — Advantages

- Gallium Nitride (GaN) has large bandgap, high electron saturation velocity, excellent thermal properties, good radiation hardness properties, and good chemical stability
- Consequently, high electron mobility transistors (HEMTs) fabricated on epitaxially grown GaN-on-SiC wafer can
  - Operate at high frequencies
  - Deliver high RF output power
  - Offer good linearity
  - Enhance power added efficiency
  - SiC has excellent thermal conductivity
  - Perform reliably at elevated temperatures & in radiation environments

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# High Power Amplifier

## — Brief Set of Requirements

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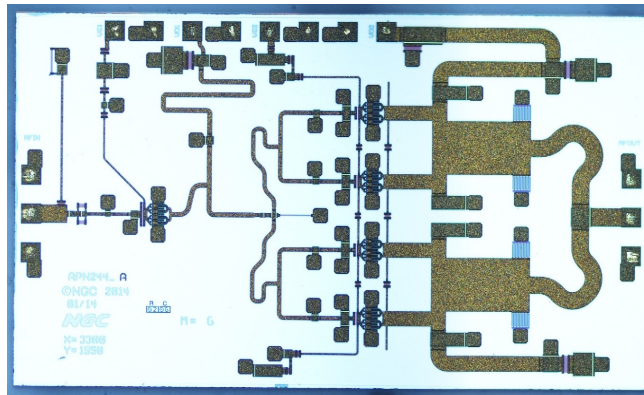
- Forward link frequency range: 23.15 to 23.55 GHz
- Output saturated power ( $P_{\text{Sat}}$ ): 7.5 to 10 watts (CW)
- Power added efficiency (PAE) at  $P_{\text{Sat}}$ : 20-25%
- Small signal Gain (driver & power amplifier): >25 dB
- RMS Error Vector Magnitude (RMS EVM): < 6%
- Gain flatness:  $\pm 1$  dB
- Input/output return loss: < 10.0 dB

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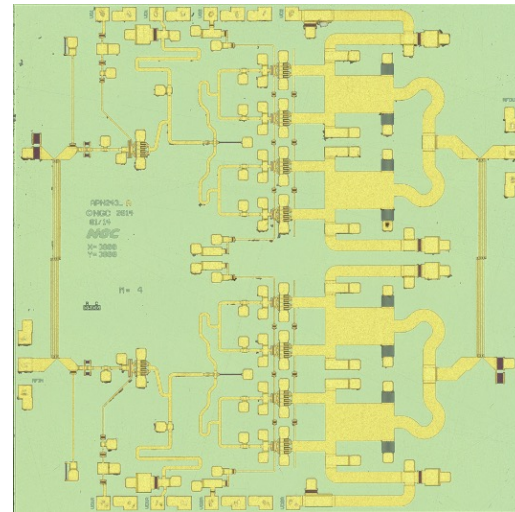
# GaN MMIC Driver and Power Amplifier Chips

Northrop APN244 — GaN Driver Amplifier



X = 3.3 mm; Y = 1.95 mm  
0.2  $\mu$ m gate length  
4 mil SiC substrate

Northrop APN243 — GaN Power Amplifier



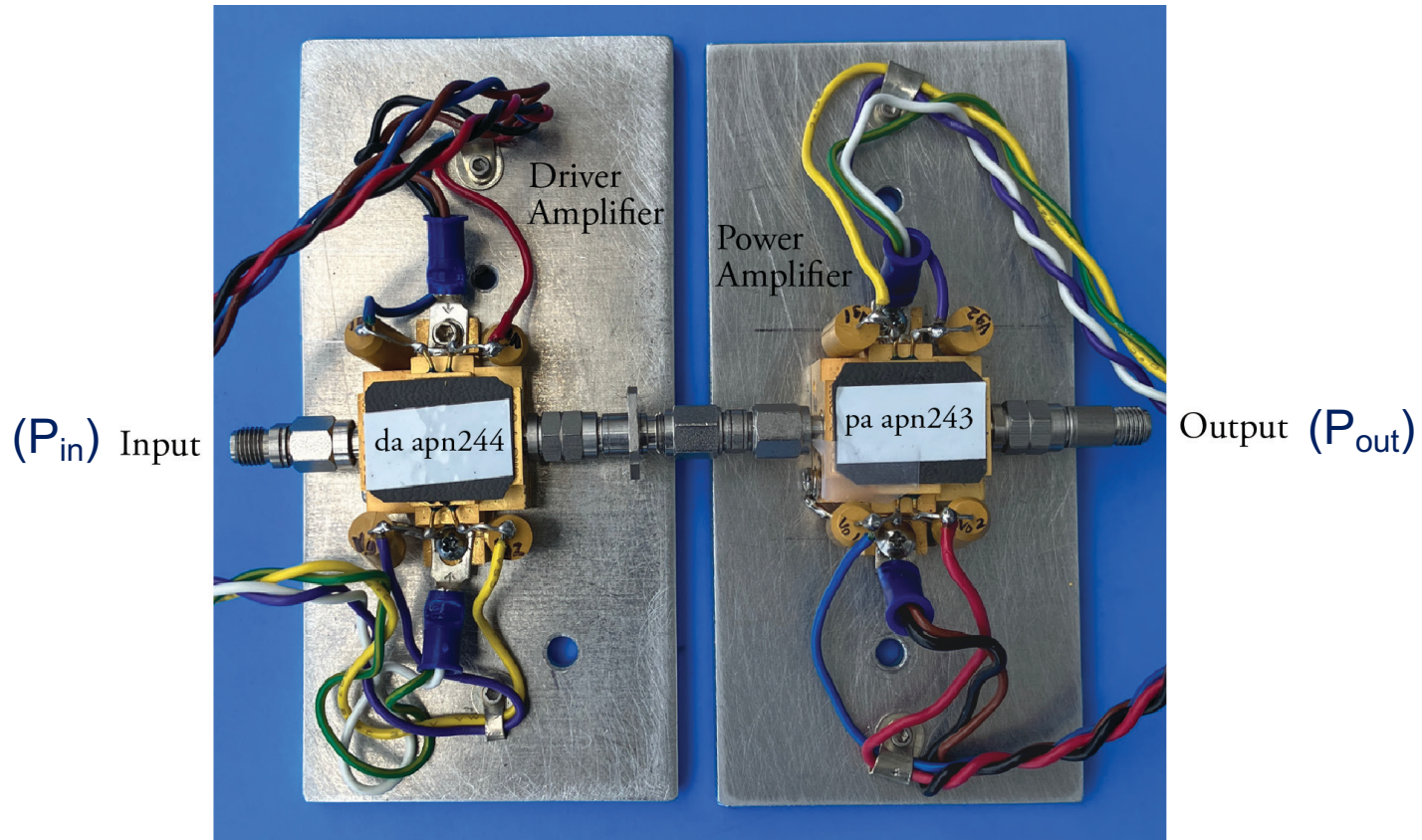
X = 3.8 mm; Y = 3.8 mm  
0.2  $\mu$ m gate length  
4 mil SiC substrate

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# Prototype Single-Ended High Power Amplifier (Interconnected Driver & Power Amplifier Modules)

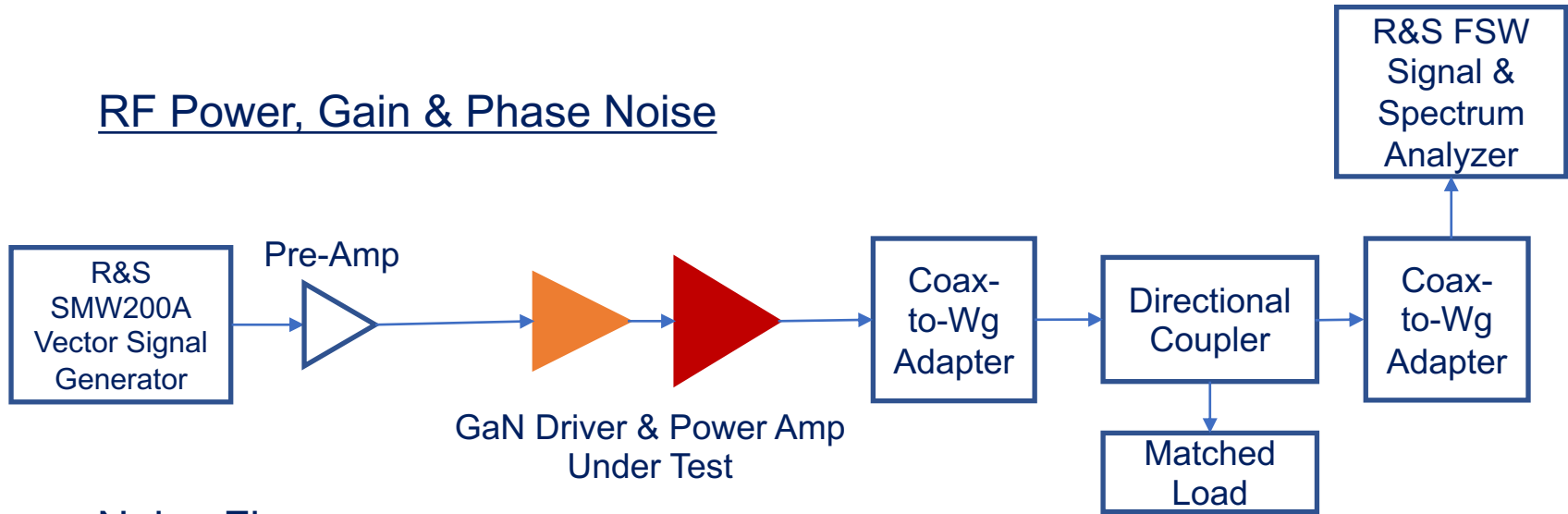
The design is validated by characterizing the interconnected driver and power amplifier modules



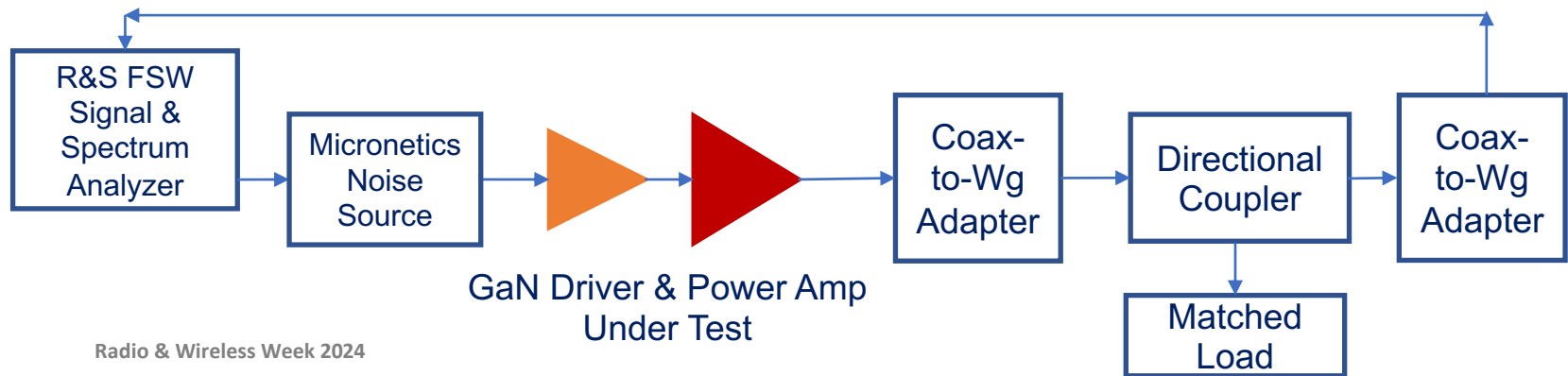
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# Measurement Test Set Up

## RF Power, Gain & Phase Noise



## Noise Figure



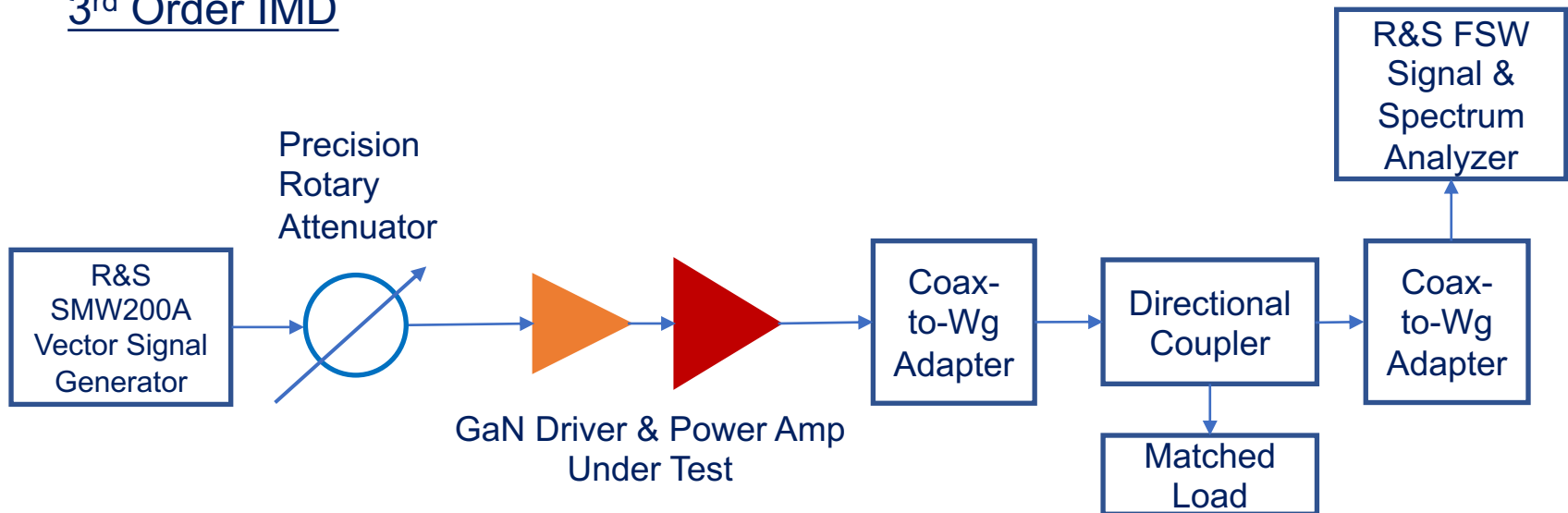
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# Measurement Test Set Up

## (Continued)

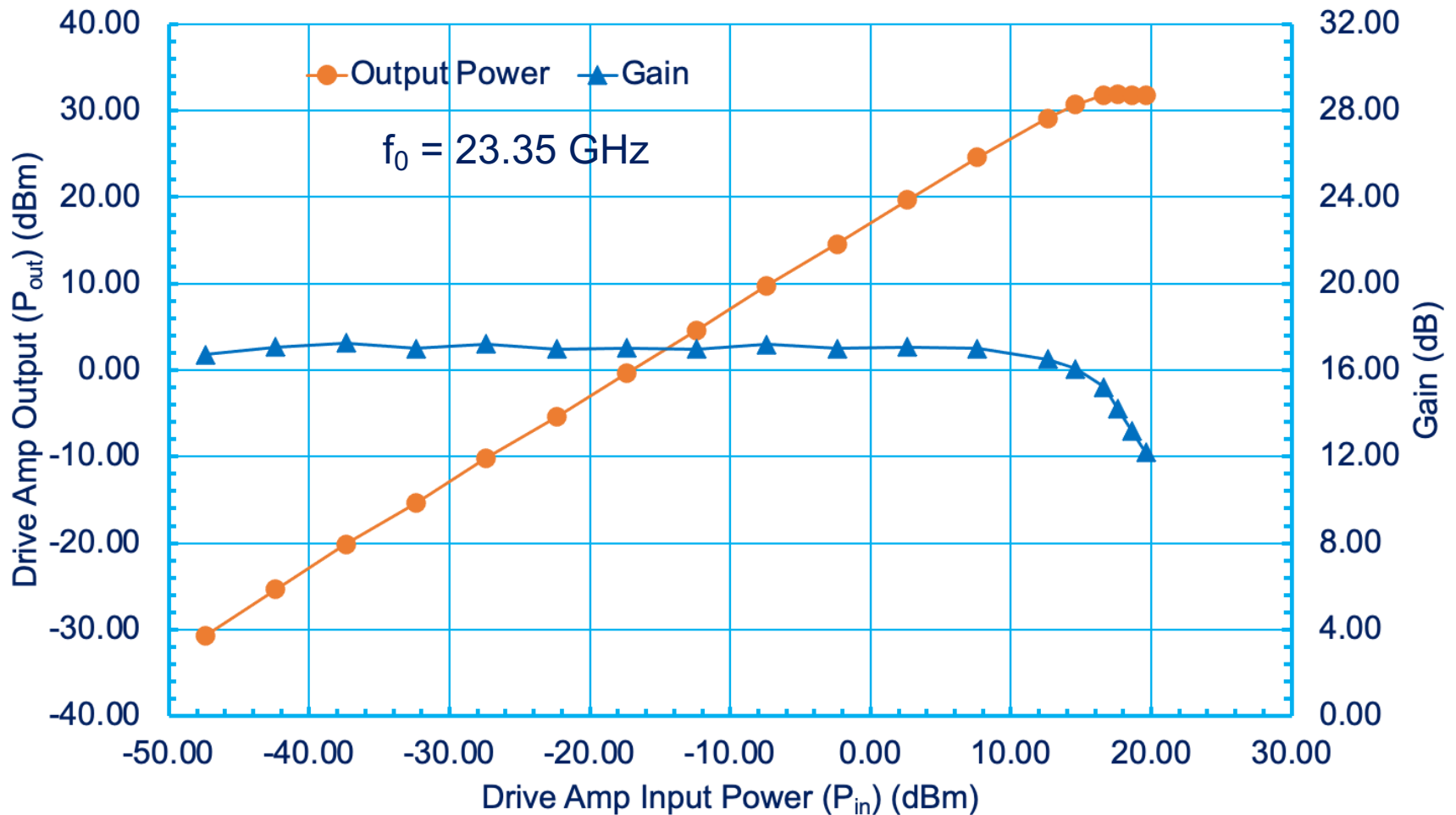
### 3<sup>rd</sup> Order IMD



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# Measured $P_{out}$ & Gain vs. $P_{in}$ (APN244 Driver Amplifier Module)



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Driver amplifier:  $V_{d1} = V_{d2} = 23.1$  V,  $I_{d1} = 0.069$  A,  $I_{d2} = 0.321$  A, and  $V_{g1} = V_{g2} = -3.9$  V.

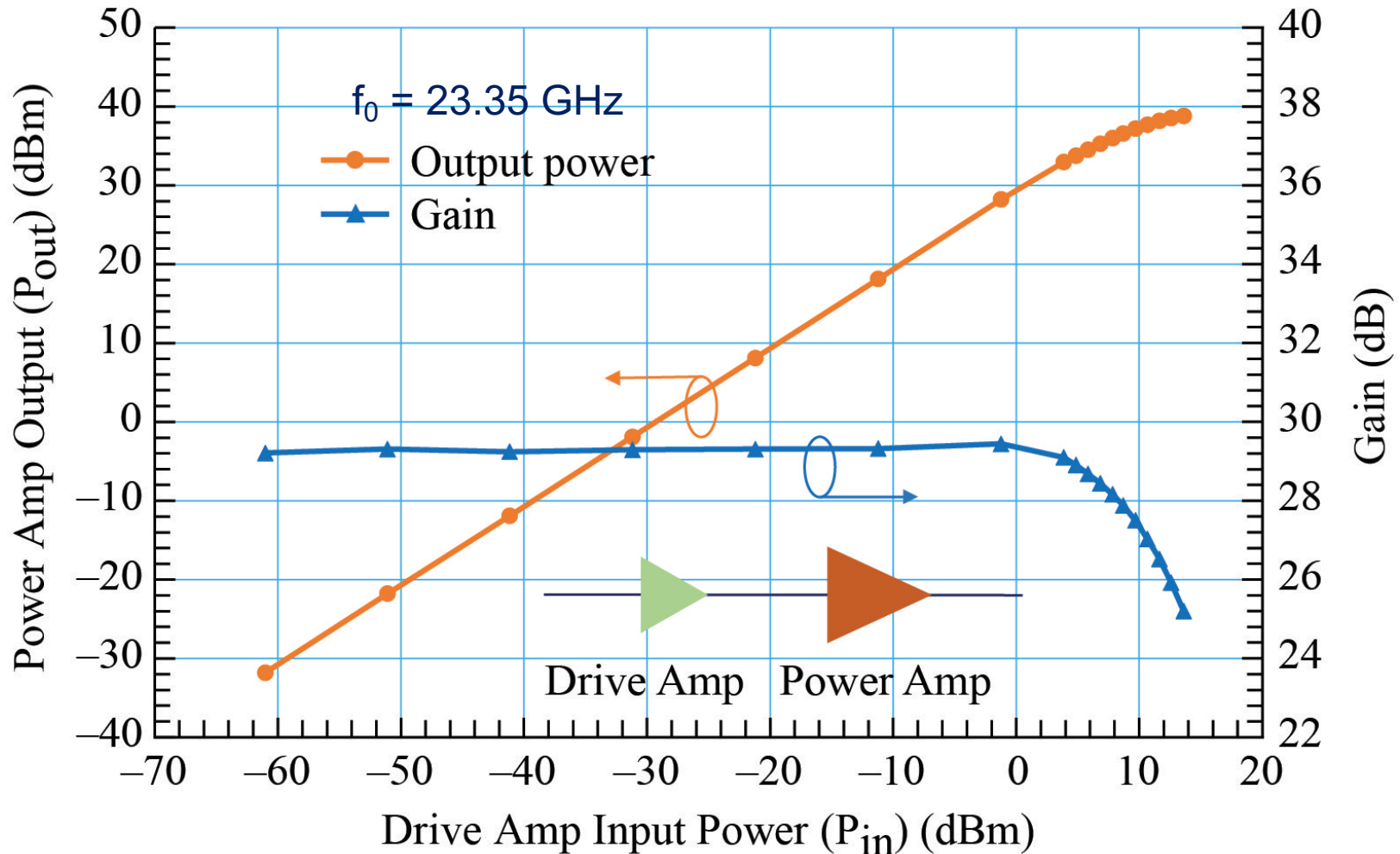
(Note: The above current values are at saturation and no attempts were made to optimize the drain/gate voltages)





# Measured $P_{out}$ & Gain vs. $P_{in}$

## (Interconnected Driver and Power Amplifier Modules)



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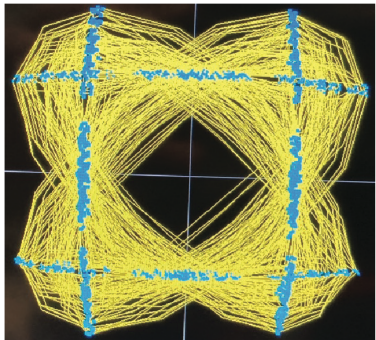
Driver amplifier:  $V_{d1} = V_{d2} = 23.1$  V,  $I_{d1} = 0.069$  A,  $I_{d2} = 0.321$  A, and  $V_{g1} = V_{g2} = -3.9$  V.  
 Power amplifier:  $V_{d1} = V_{d2} = 23$  V,  $I_{d1} = 0.23$  A,  $I_{d2} = 1.03$  A, and  $V_{g1} = V_{g2} = -4.5$  V.  $T = 25$  °C

(Note: The above current values are at saturation and no attempts were made to optimize the drain/gate voltages)

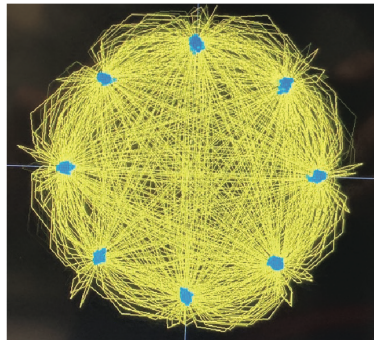




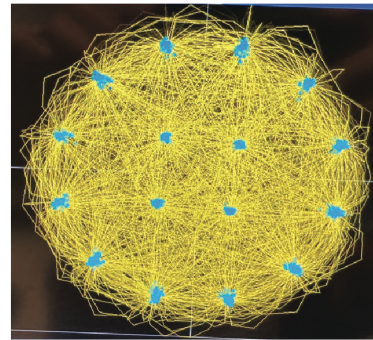
# Waveform Constellations



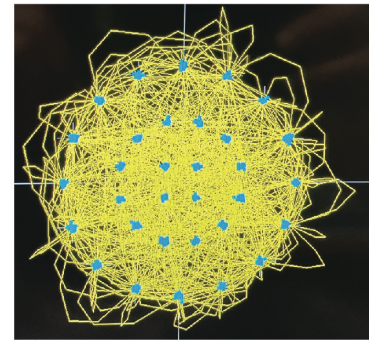
Offset QPSK



8 PSK



16 APSK

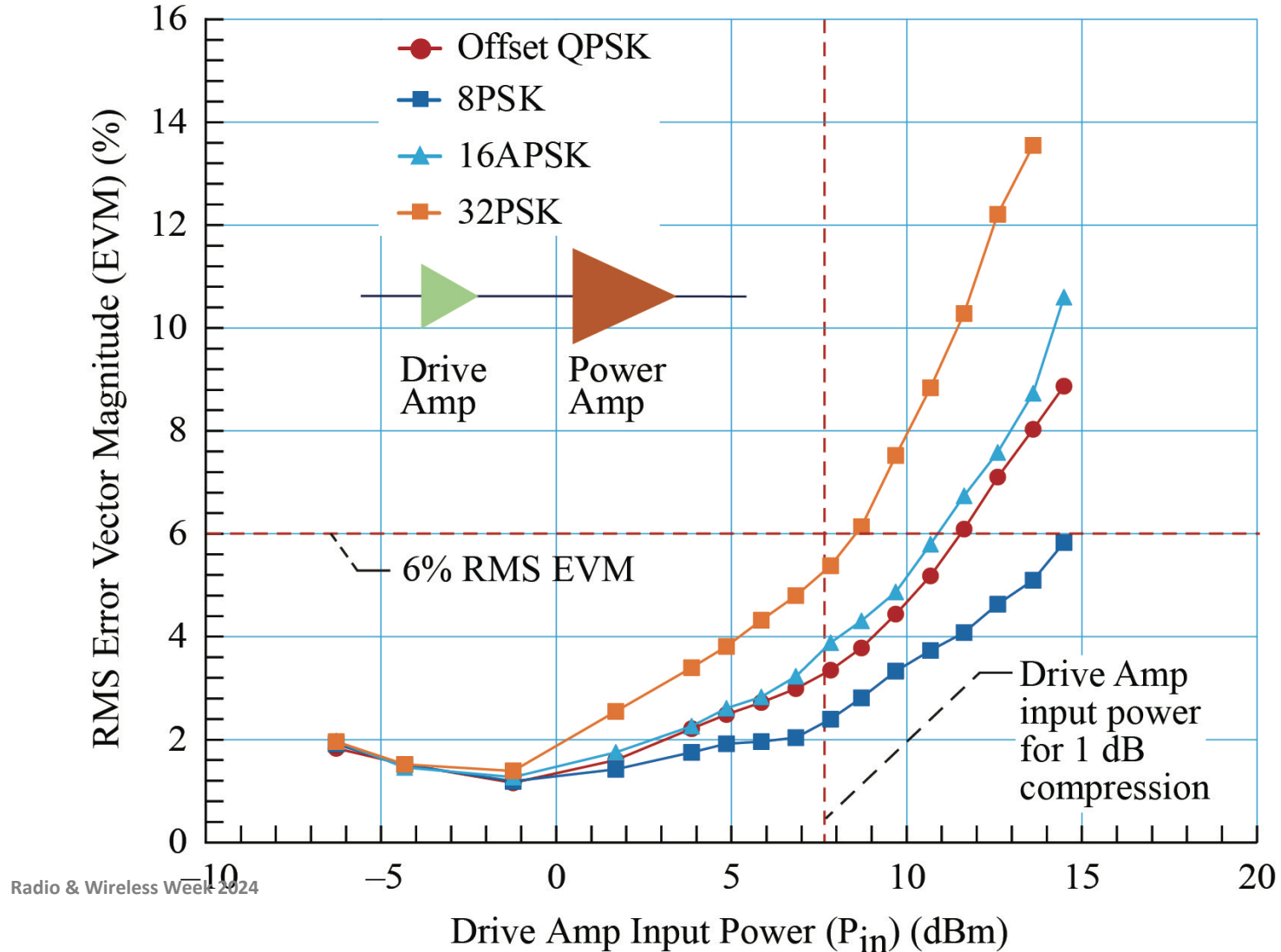


32 APSK

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# Measured RMS EVM vs. $P_{in}$ at $f_0 = 23.35$ GHz (Symbol Rate = 180 Msym/s & SRRC = 0.35)

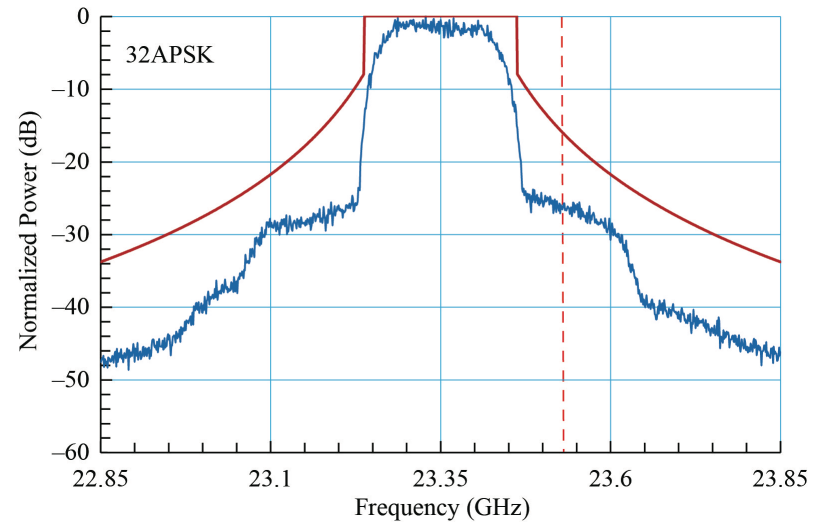
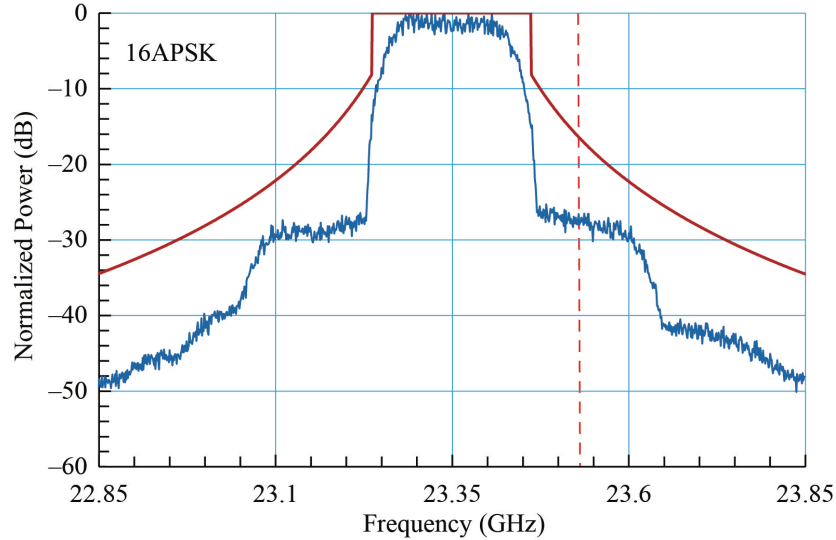
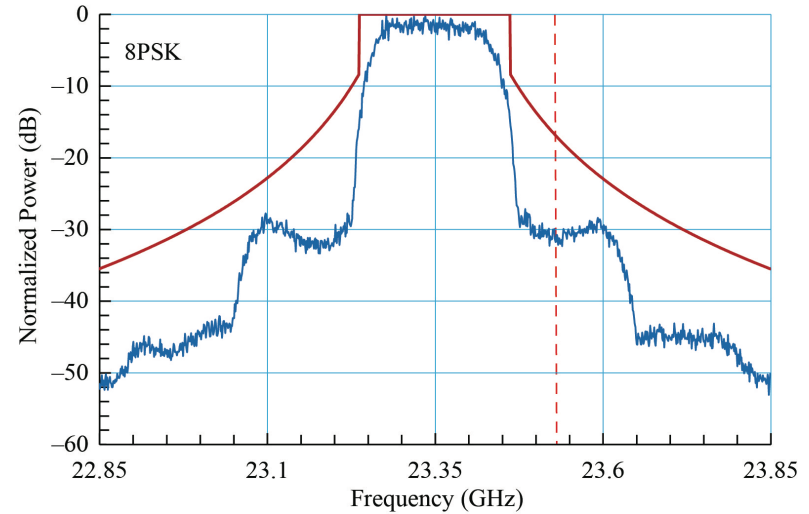
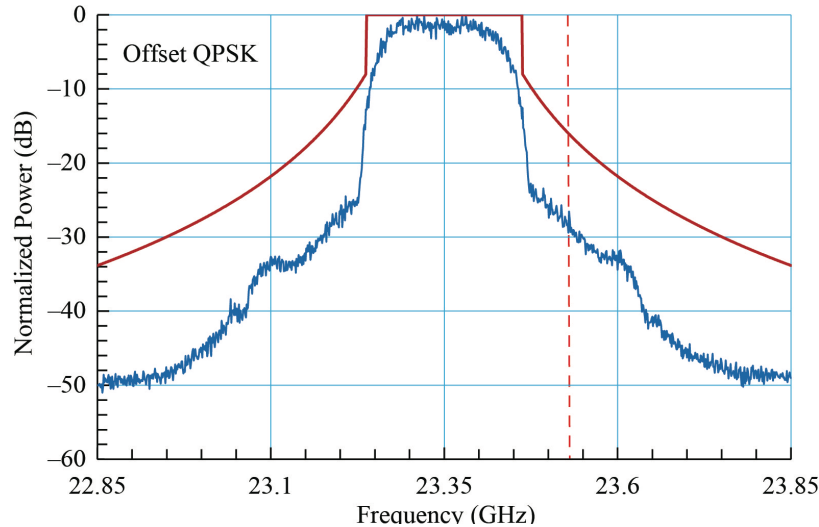


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# Measured Spectrum at $f_0 = 23.35$ GHz

(Symbol Rate = 180 Msym/s, SRRC = 0.35 & BW = 225 MHz)

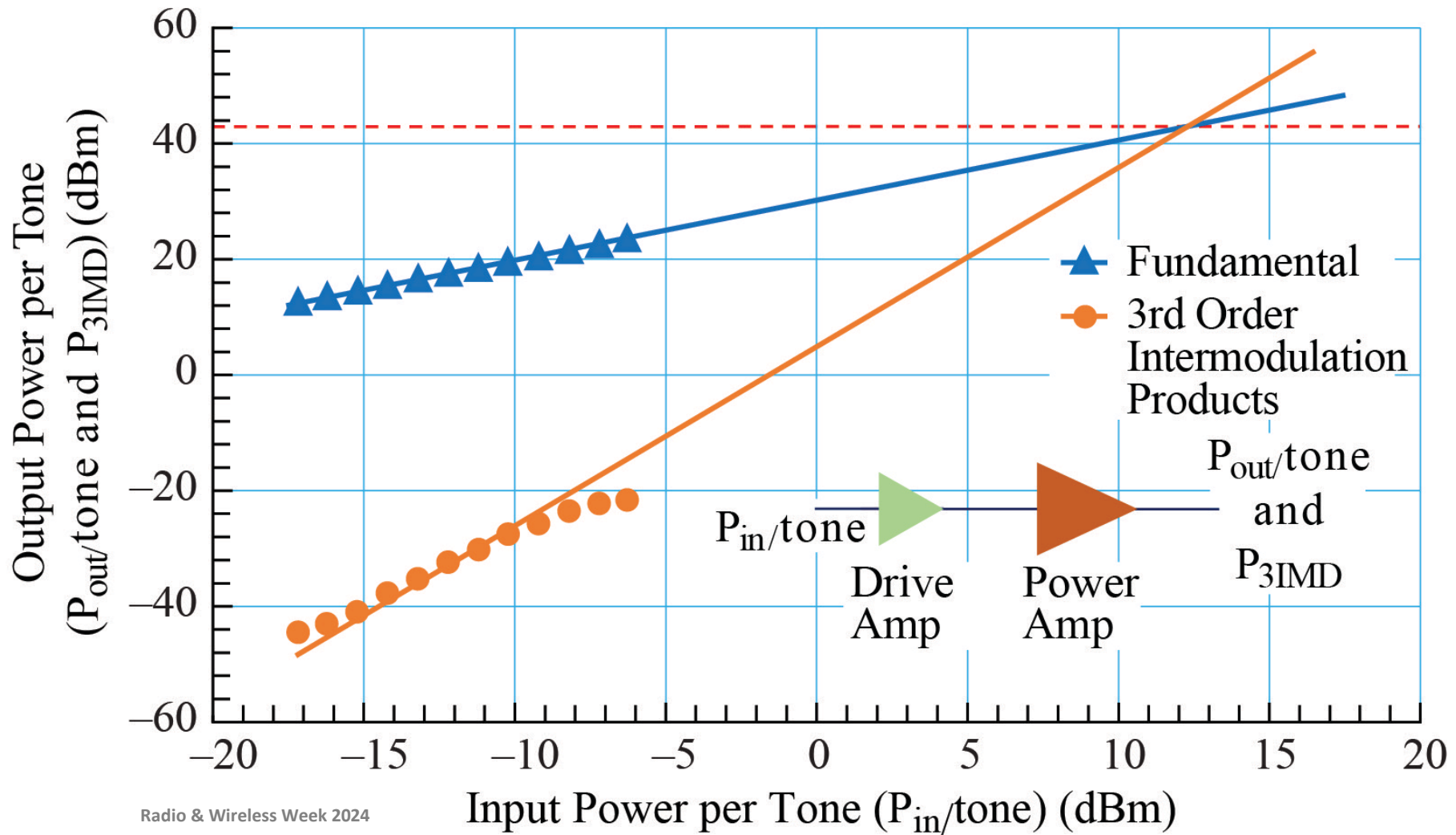


(Note: Red solid line is the NTIA emission mask)



# Measured 3rd Order IMD vs. $P_{in}$ Per Tone

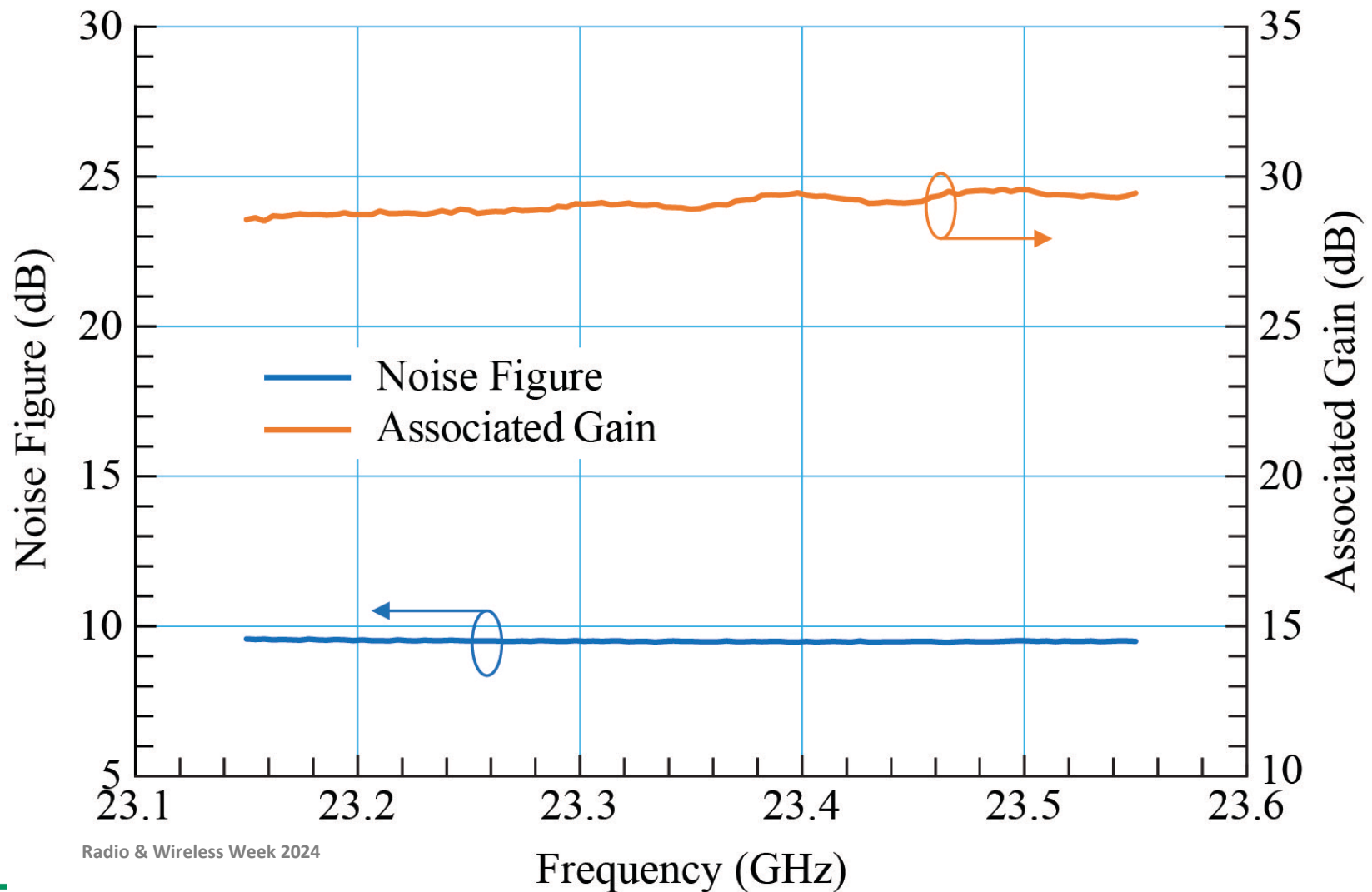
( $f_0 = 23.35$  GHz & Tone Spacing = 5 MHz)



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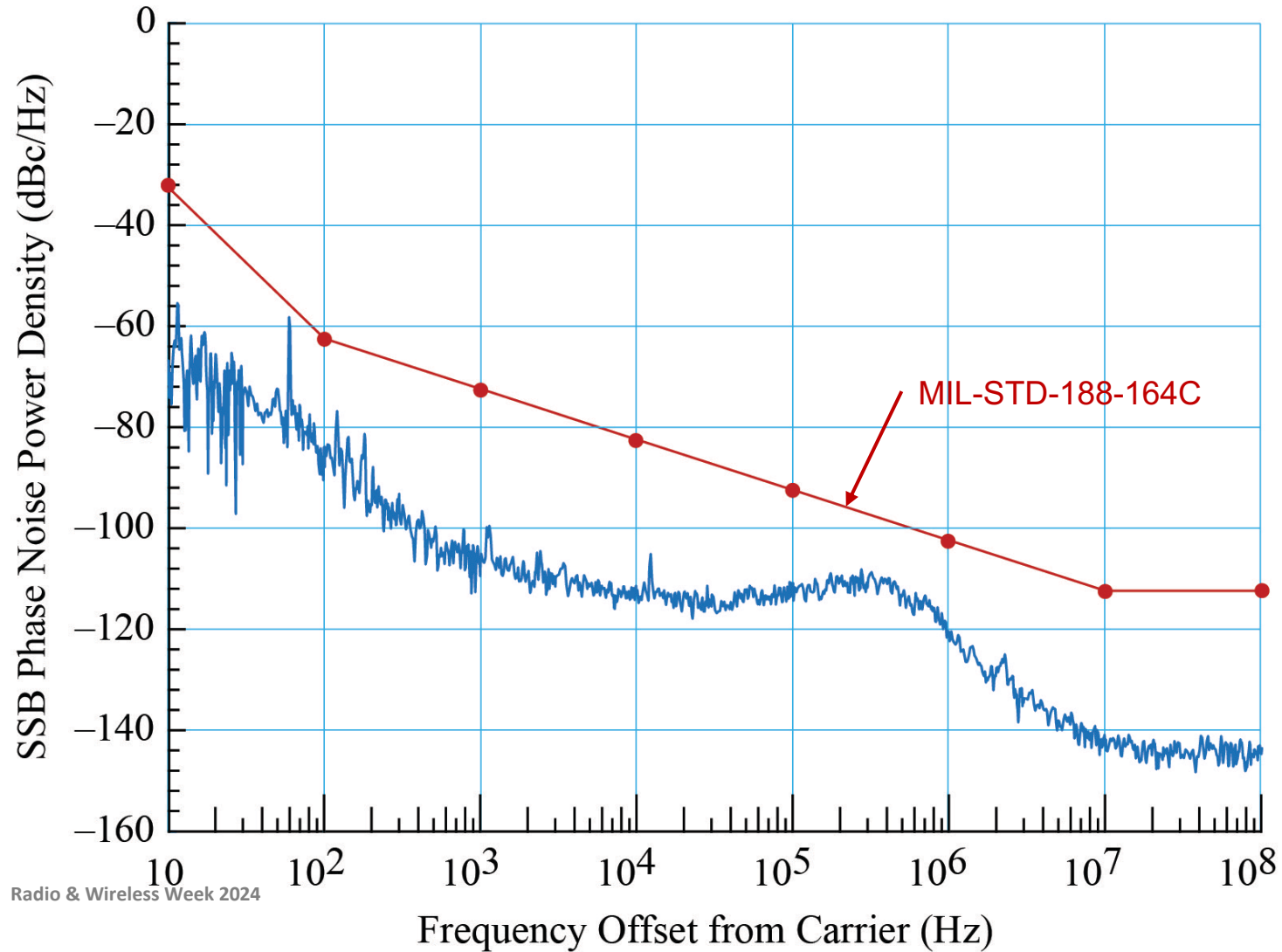


# Measured Noise Figure & Associated Gain



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# Measured SSB Spectral Phase Noise vs. Frequency Offset from Carrier at $f_0 = 23.35$ GHz



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# Test Results Summary

Parameter	Measured Value
Carrier or Center Frequency (GHz)	23.35
Saturated Output Power ( $P_{\text{sat}}$ ) (dBm)	38.8 (7.6 W)
Small Signal Gain (dB)	29.3
Peak PAE (%)	20.0
Return Loss (dB)	<10.0
RMS EVM for Offset-QPSK, 8PSK, 16APSK, & 32APSK waveforms (%) ( $P_{\text{in}}$ is at the 1-dB compression point)	<6
Out-of-Band Spectral Regrowth (dBc)	< -26.0 (Spectrum compliant with NTIA emission mask)
OIP3 (dBm)	42.0
Noise Figure (dB)	<9.5
SSB Phase Noise Spectral Power Density (dBc/Hz) ( $P_{\text{in}}$ is at the 1-dB compression point)	Compliant with MIL-STD Mask

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# Conclusions & Discussions

- Advantages of GaN for NASA's lunar proximity communication applications are highlighted
- Design of a GaN HEMT based MMIC HPA is presented
- The design is validated by characterizing the interconnected driver and power amplifier modules
- The measured  $P_{out}$ , Gain, PAE, RMS EVM for Offset QPSK, 8PSK, 16APSK, and 32APSK constellations, 3rd order IMD products, noise figure, and SSB phase noise are presented and test results summarized
- The HPA can enable proximity forward links between the orbiting Gateway/relay satellites and the lunar surface elements and cross links between relay satellites

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**Thank You  
&  
Glad to Answer any  
Questions?**

